Performance and Monitoring of LUX-ZEPLIN's Outer Detector

Megan Carter
(On behalf of the LZ collaboration)

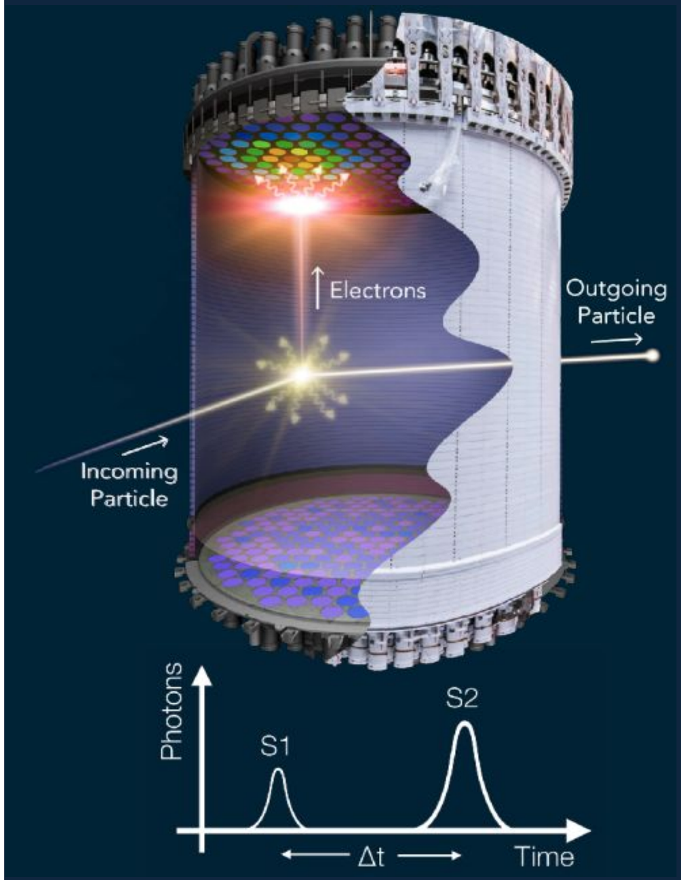
Supervisors:
Prof. Sergey Burdin, Dr Ewan Fraser

LUX-ZEPLIN

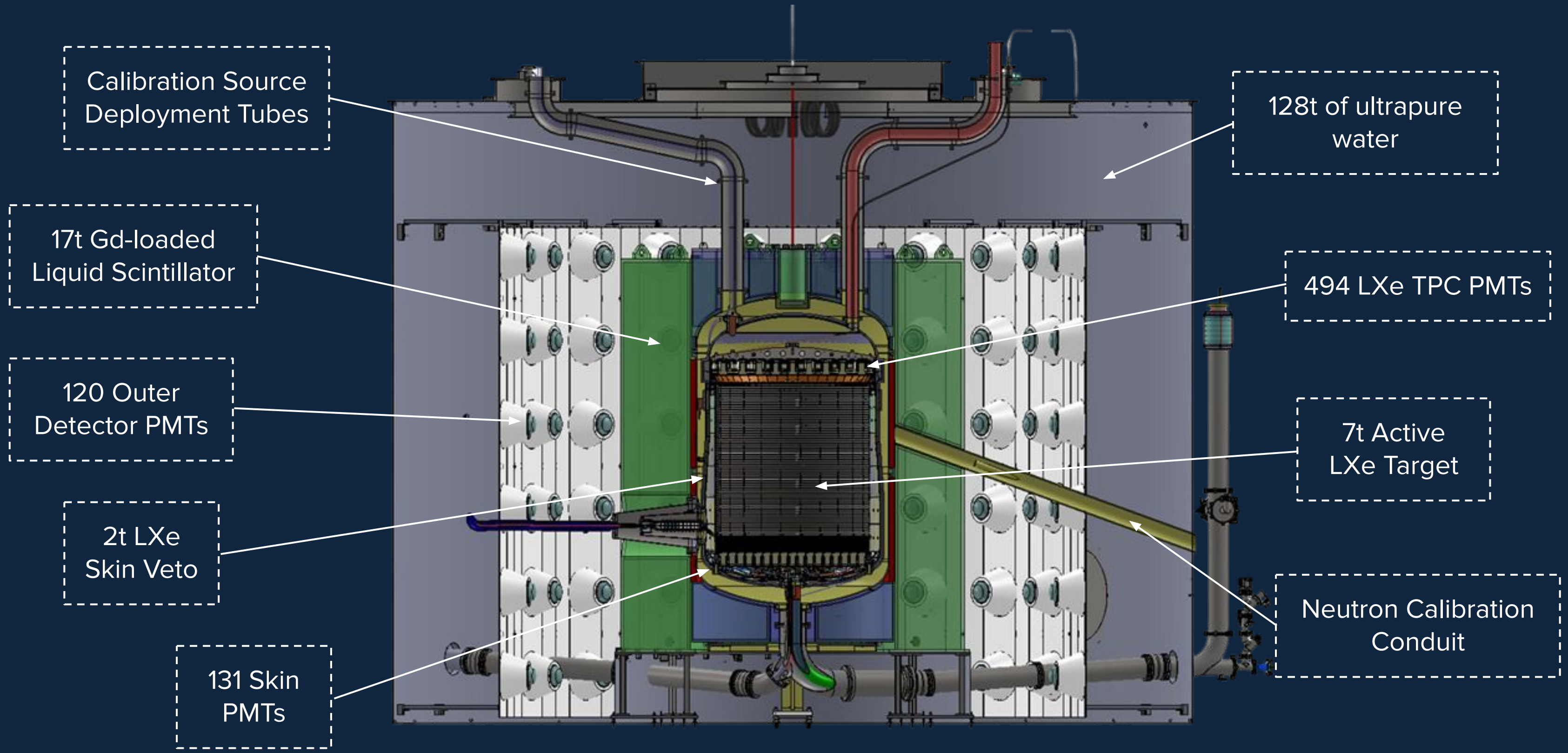
LUX-ZEPLIN (LZ) is a Dark Matter direct detection experiment, located a mile underground at SURF, South Dakota.

- Employs a cylindrical dual-phase time projection chamber (TPC) containing 7 tonnes of active liquid xenon (LXe).
  - ➢ **Primary aim of detecting WIMP-xenon nucleus scattering interactions**

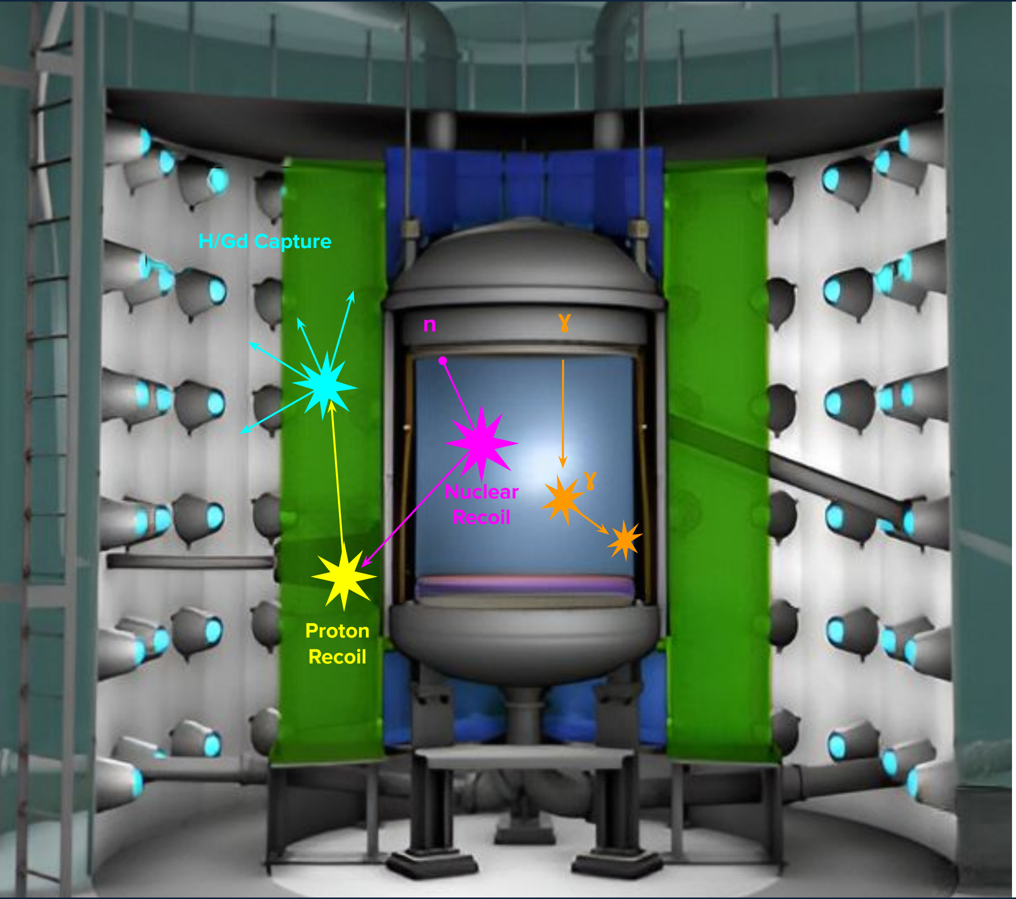
- However surrounding materials produce backgrounds that can mimic WIMP-like signals:
  - Nuclear recoils produced through neutron scattering.
  - Electron recoils from e- and γ-ray scattering.
- LZ surrounds its TPC with a veto system to reduce and identify these background events.

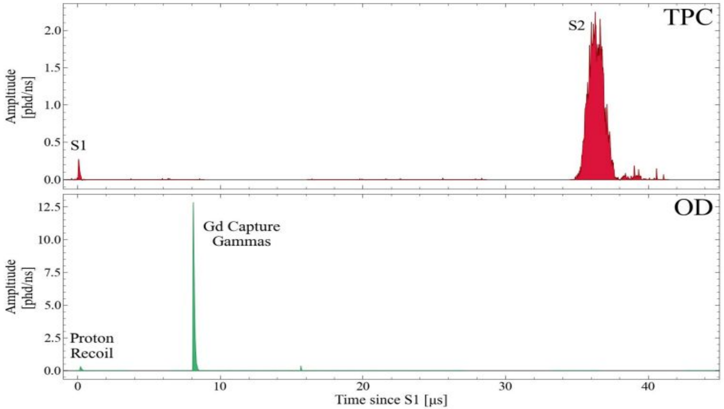


LUX-ZEPLIN


Calibration Source Deployment Tubes
17t Gd-loaded Liquid Scintillator
120 Outer Detector PMTs
2t LXe Skin Veto
131 Skin PMTs
128t of ultrapure water
494 LXe TPC PMTs
7t Active LXe Target
Neutron Calibration Conduit

Outer Detector (OD)



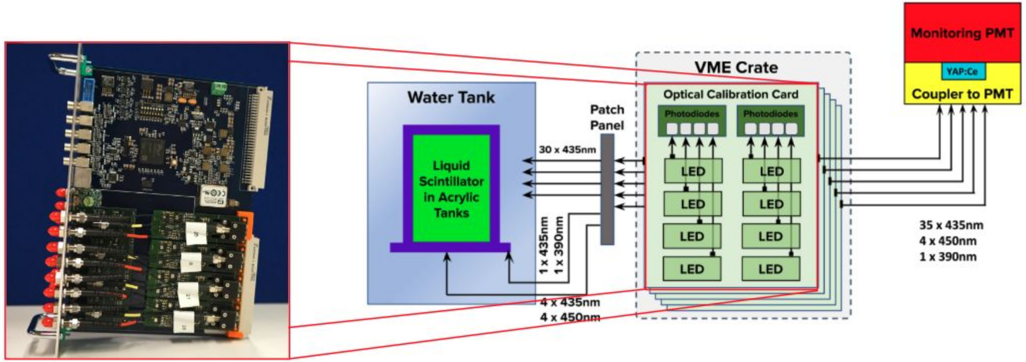


- A WIMP scattering in a noble element detector will only deposit energy in the TPC, not the surrounding materials.
- Using the veto systems we can tag:
  - Prompt events from gamma-rays and proton recoils
  - Neutron captures on hydrogen or gadolinium

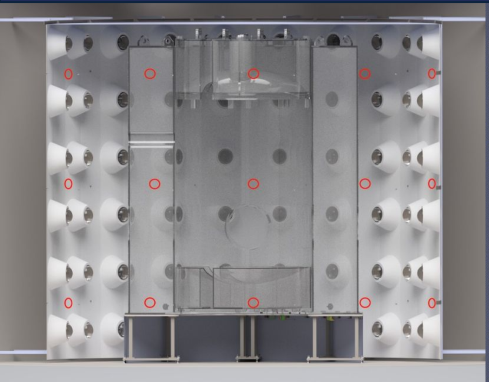
Optical Calibration System

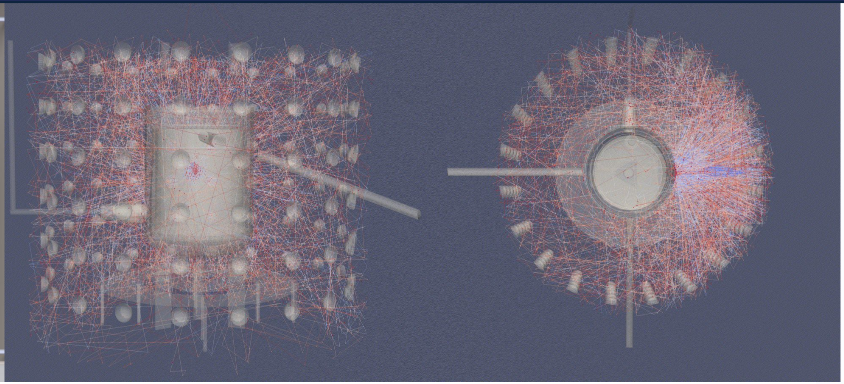
The Optical Calibration System (OCS) is used to monitor and calibrate the OD PMTs, and more recently to monitor light transmission in the OD.

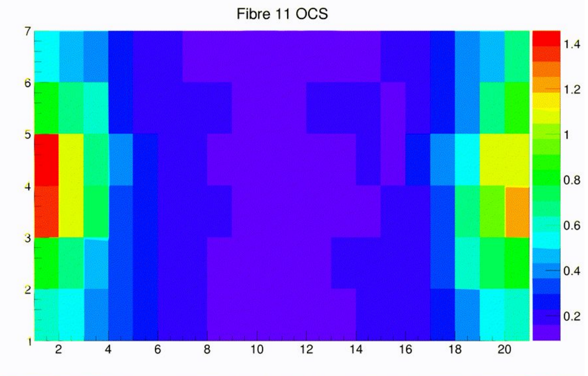
- Duplex optical fibres to inject controlled pulses of light produced by LEDs into the OD at 30 locations.
- LEDs of wavelength 435nm used in order to match the peak wavelength and quantum efficiency of the OD PMTs and the scintillation light from the GdLS.



OCS Measurements



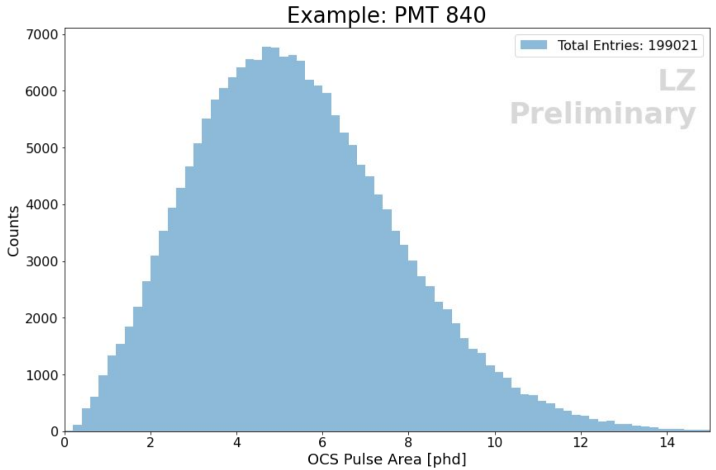




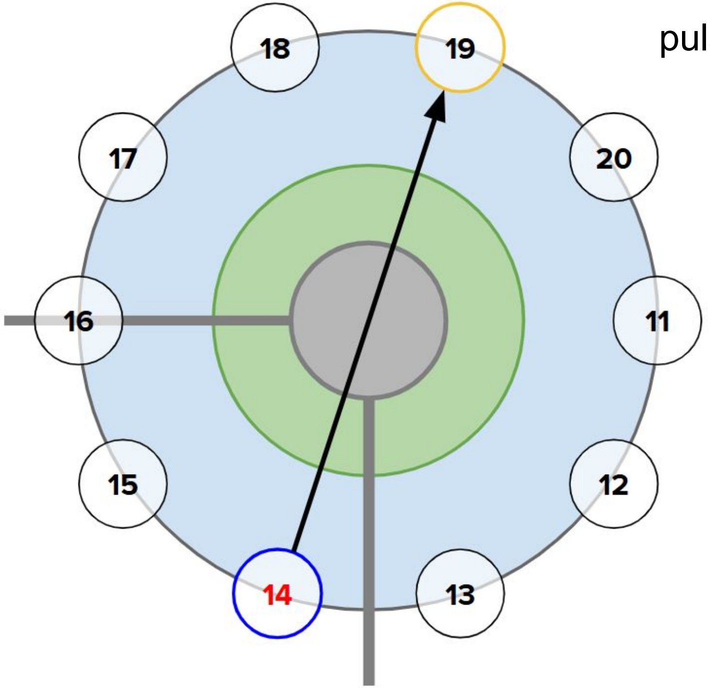
Set numbers of photons injected through different fibres around the perimeter of the OD.

Measurements are taken monthly, and the responses from the PMTs are analysed for both performance monitoring and calibration purposes.

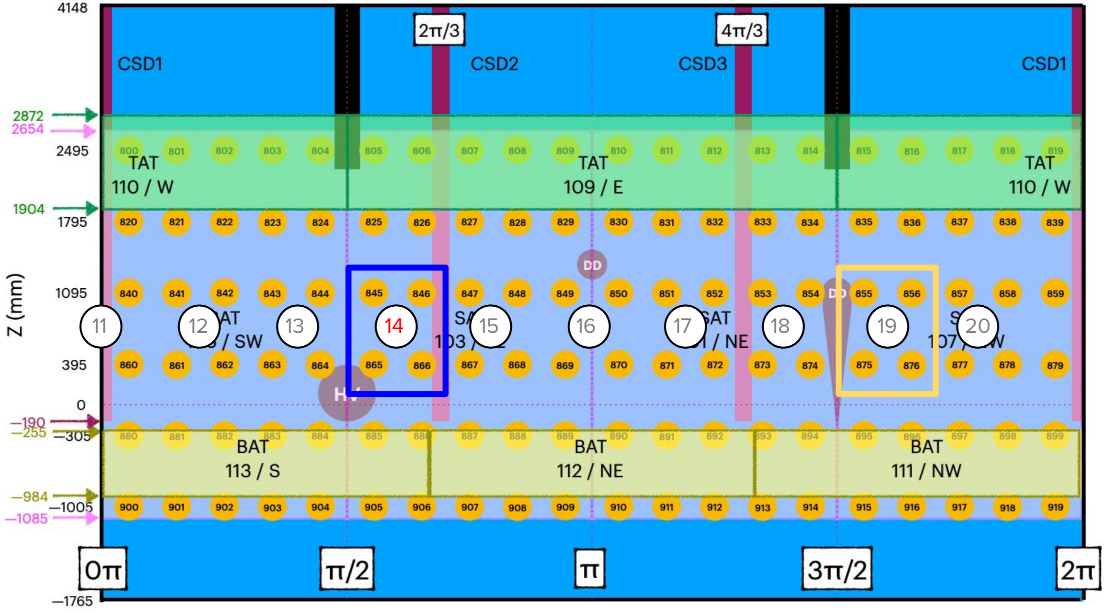
Example OCS pulse from PMT 840



Light Transmission Monitoring

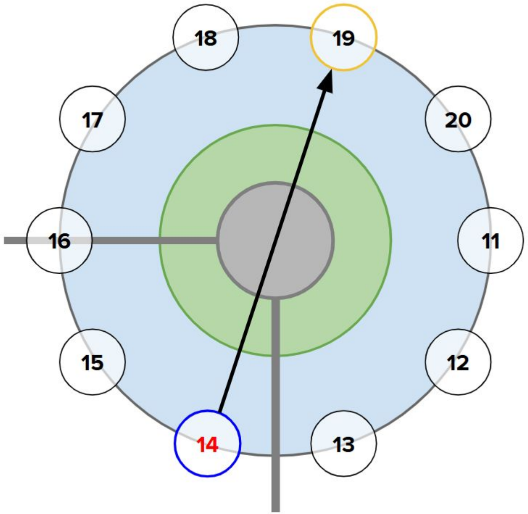


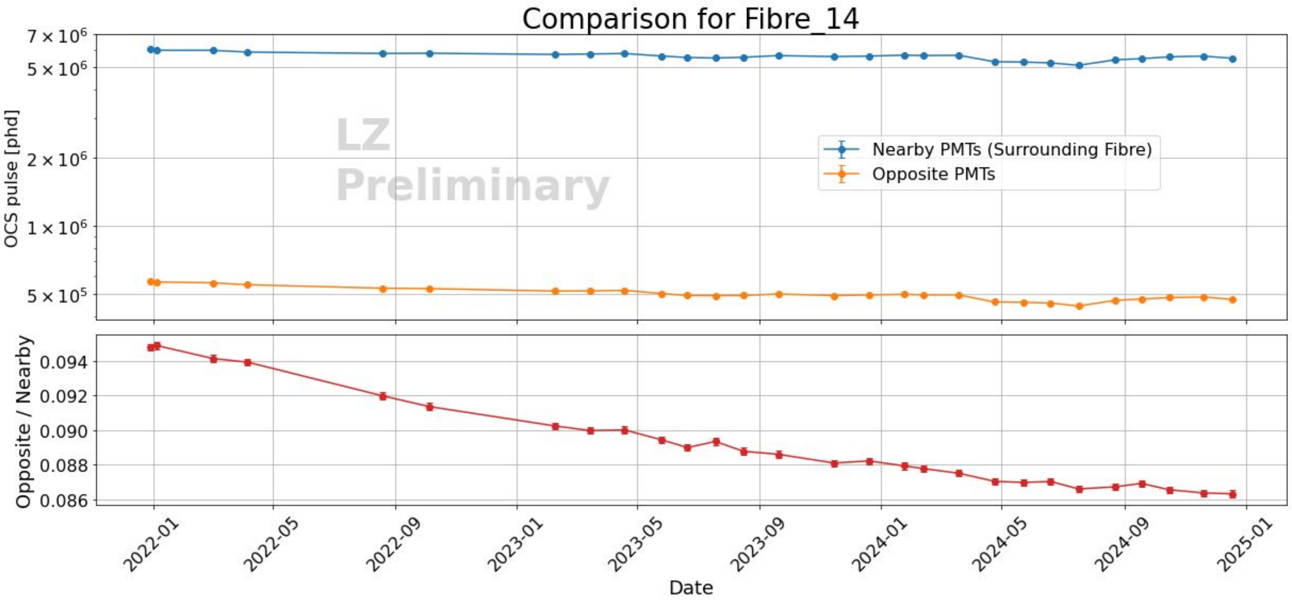
For monitoring light transmission, the total photons detected from OCS pulses are compared between the PMTs on either side of the tank.



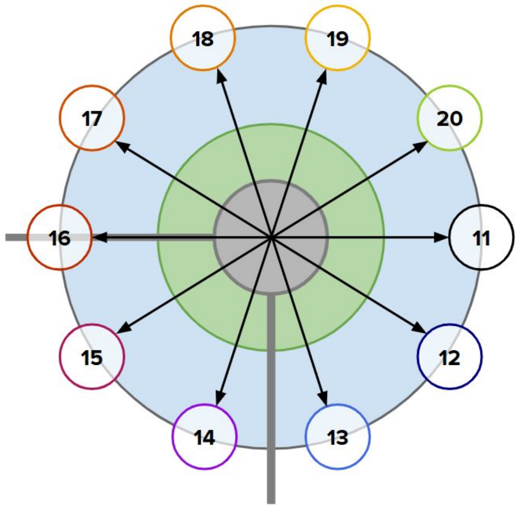
Example: Fibre 14

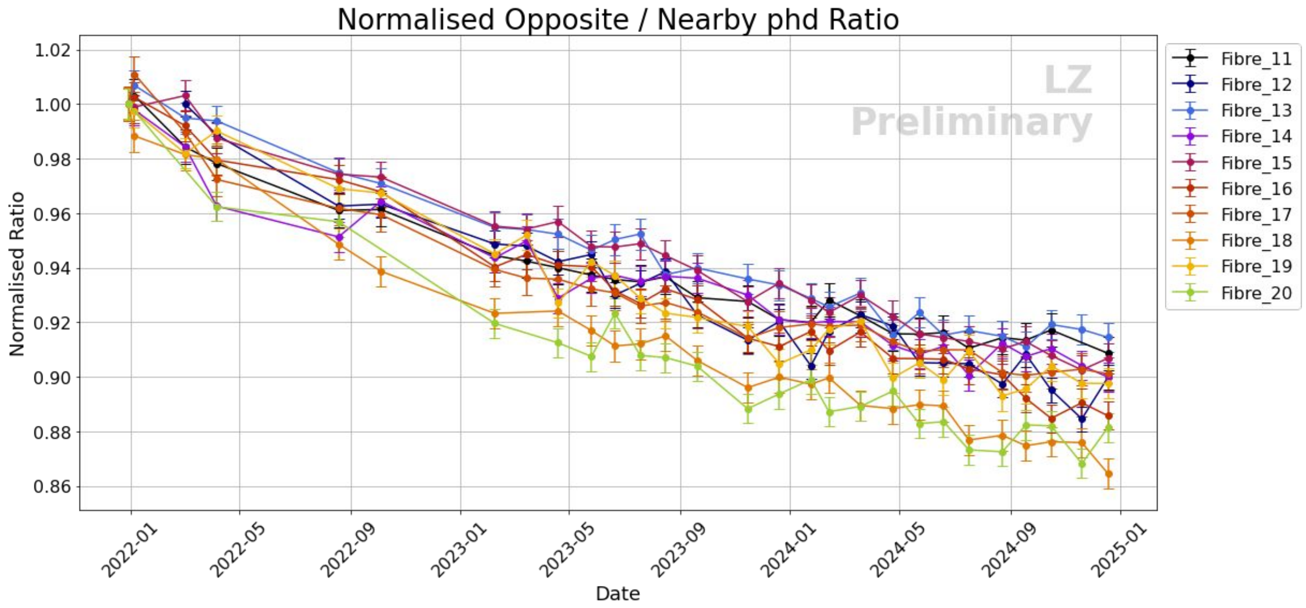
The total OCS pulse area in photons detected (phd) is calculated for the four PMTs surrounding the fibre and the four PMTs opposite to it, and their ratio is then compared:





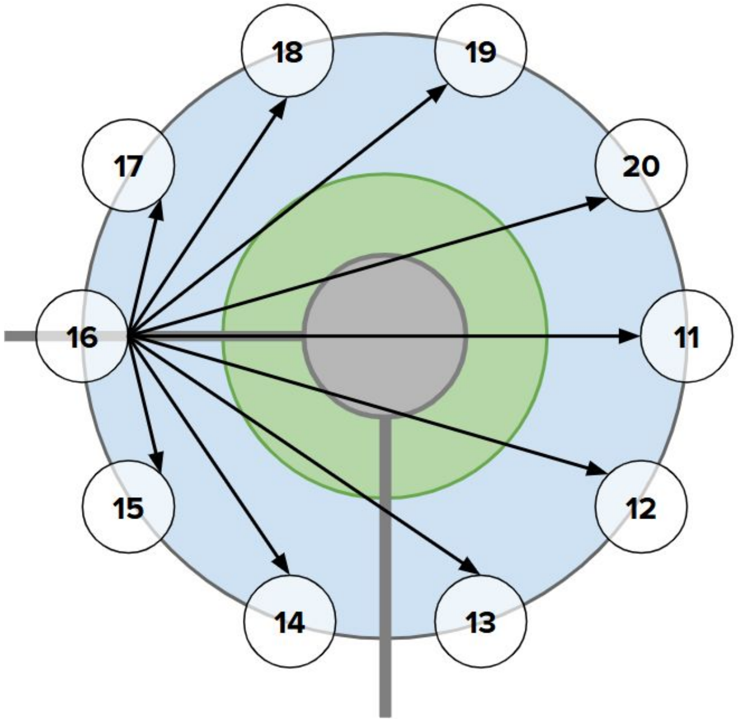
All Fibres

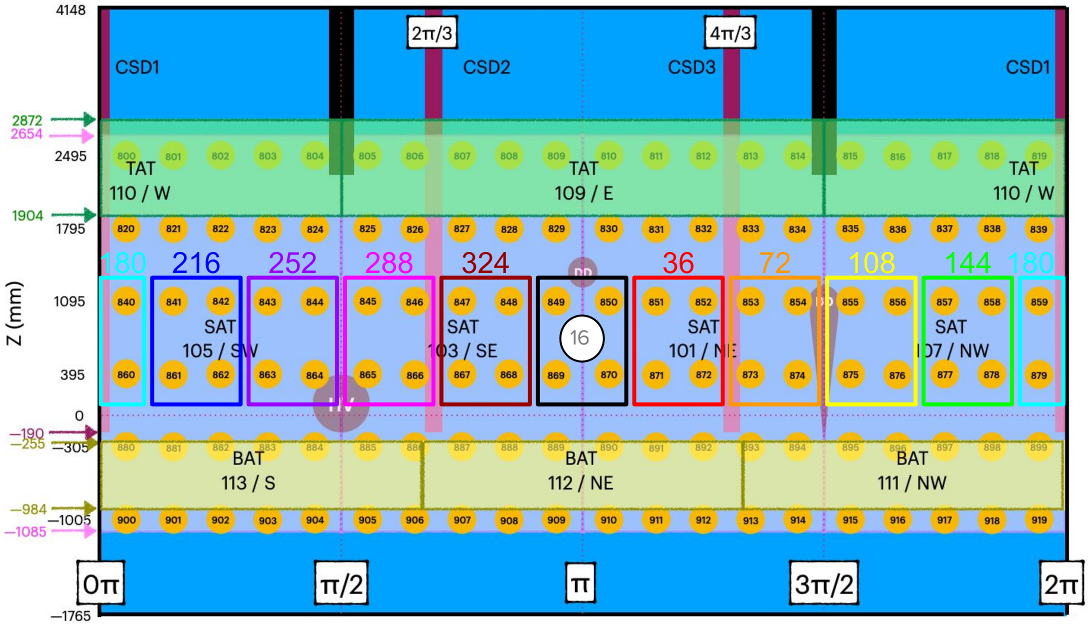




➢ **Decrease of ~10% over the past three years seen across ALL fibres - suggests degradation of OD medium transmission/reflection properties (not degradation of PMT quantum efficiency).**

Full Rotation

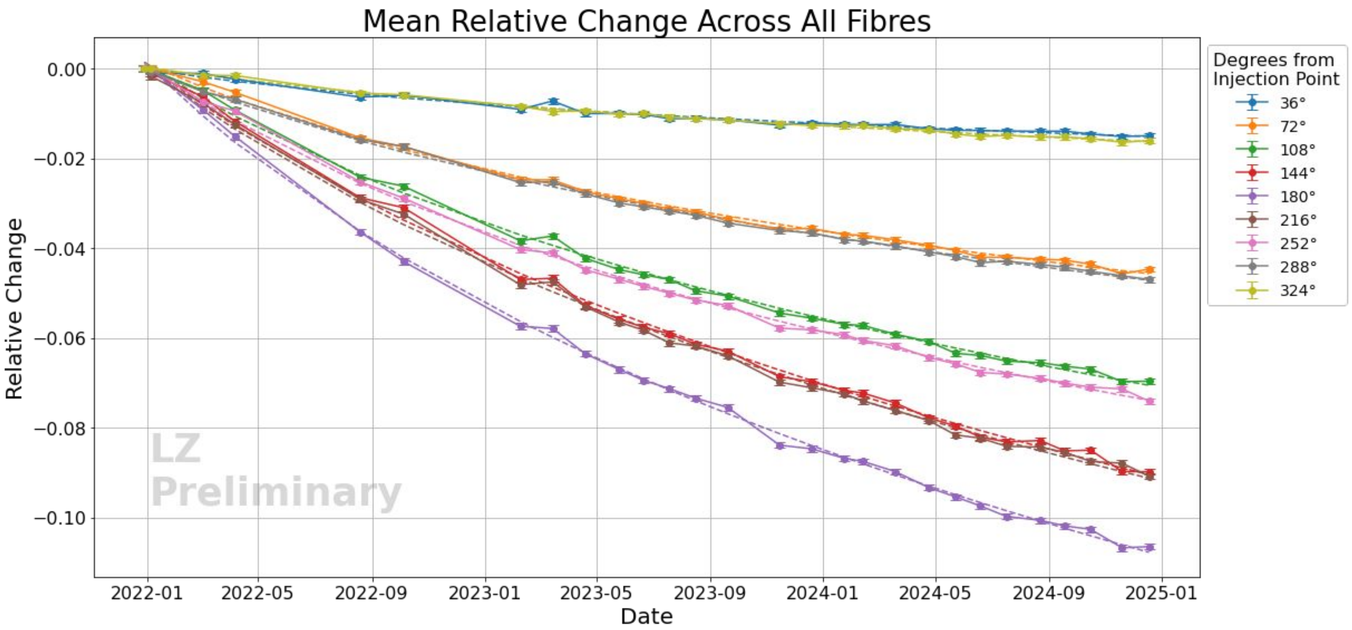




Full Rotation

The further away from the fibre, the larger the decrease.

- ➢ More reflection and transit through different media, the greater the reduction.



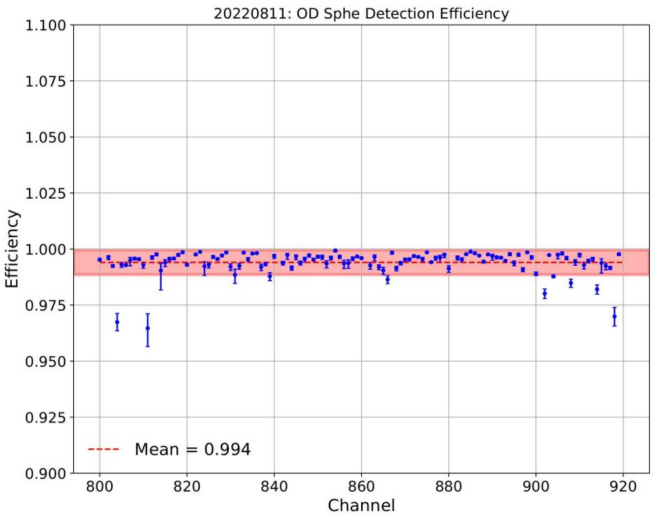
Similar decreases were seen by Daya Bay, where over 3 years an approximate 4% light yield degradation was observed for light passing 2 m of Liquid Scintillator which would correspond to 36-42 degrees angles in LZ.

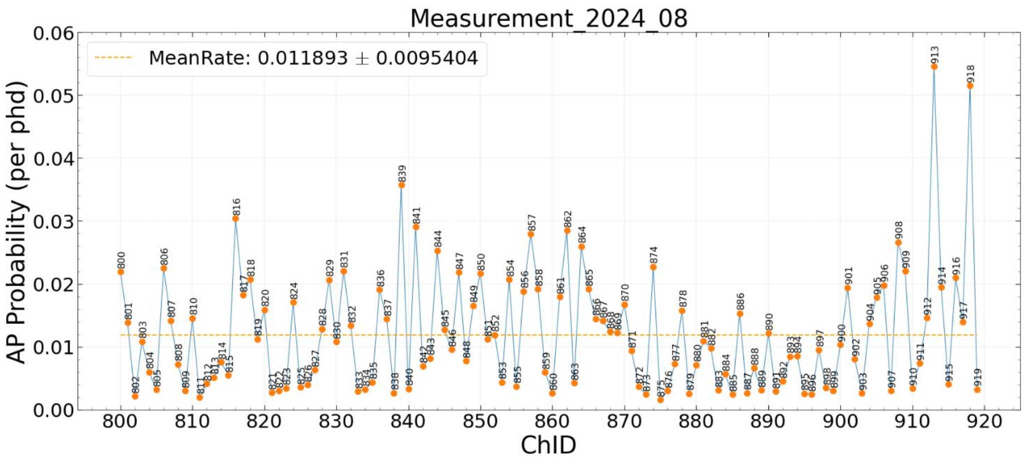
High light yield guarantees that small decrease in the light transmission doesn't affect the detector performance.

OCS - PMT Monitoring

The OCS is also used to monitor and calibrate the 120 PMTs from the Outer Detector

- **SPhE Detection Efficiency ~99%**
- **Afterpulsing rates remain low at ~1%**





Afterpulsing rates are calculated per OCS phd:

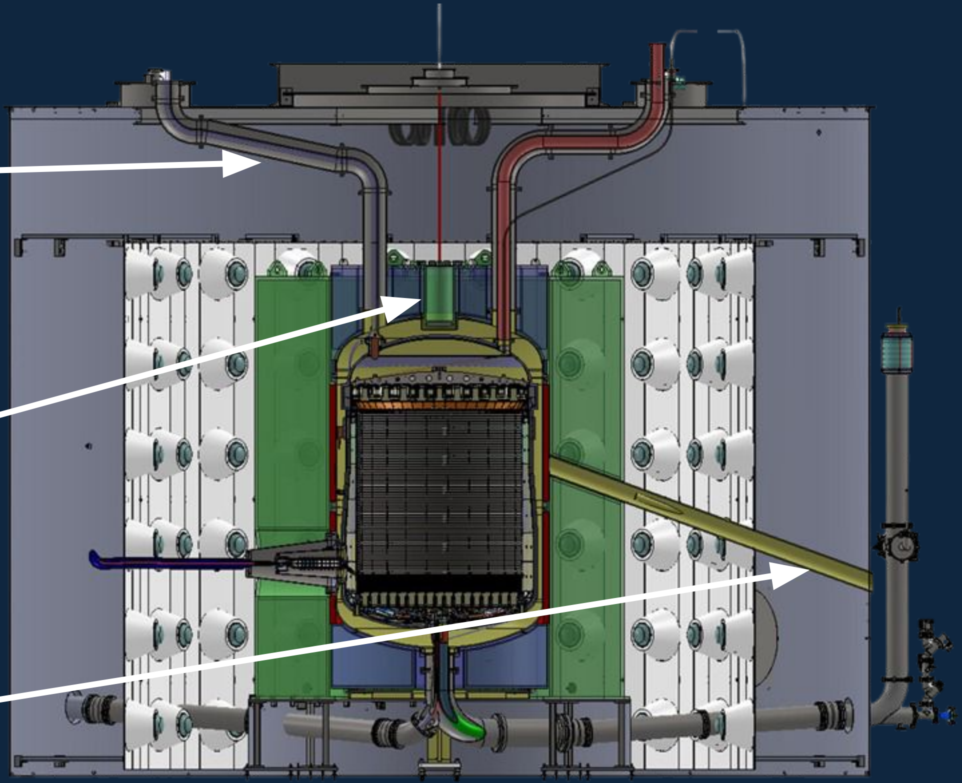
$$Rate\ of\ AP\ per\ phd = \frac{Number\ of\ Afterpulses}{OCS\ phd}$$

Source Deployment

1. Three external CSD tubes - neutrons and gammas (AmLi, Cf-252 and Th-228). Lowered to various fixed Z positions.

2. Photoneutron sources: YBe. Lowered into the detector above the tungsten shield.

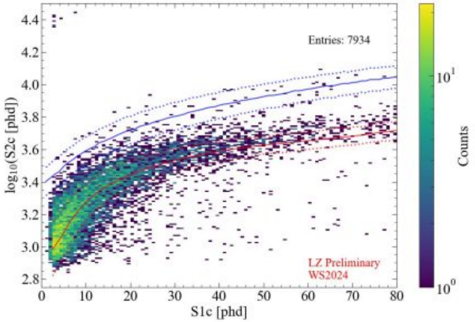
3. 2 neutron conduits: one horizontal, one angled, used for localised NR calibrations using DD neutron generator.

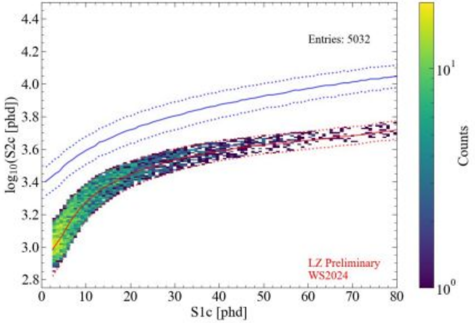


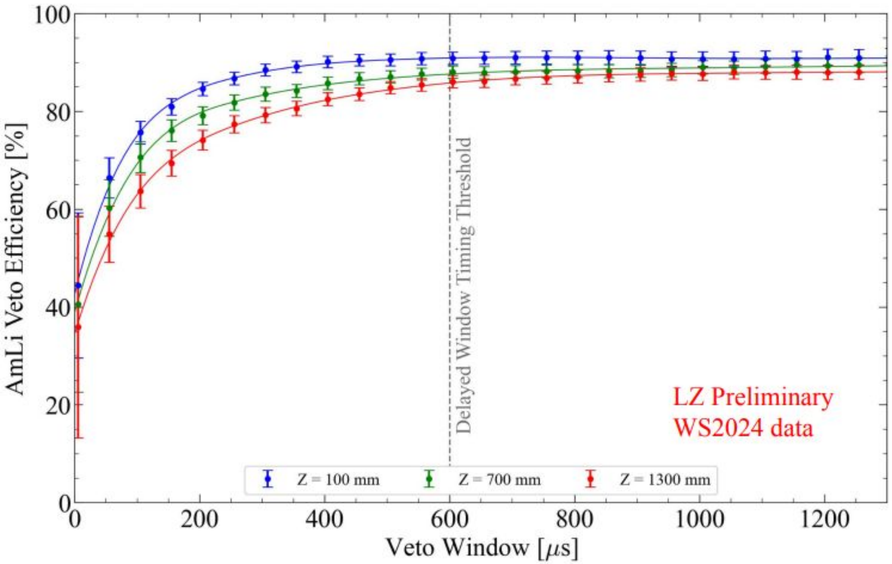
Tagging Efficiency

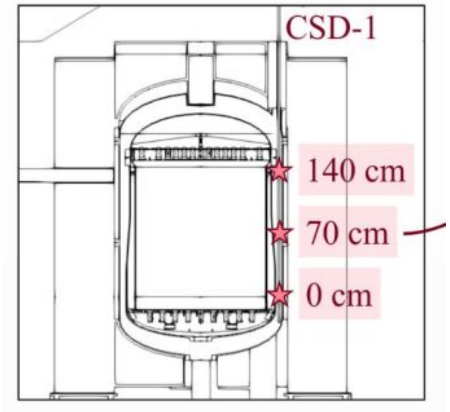
Efficiency and false veto fraction are assessed using different windows and thresholds while also accounting for detector geometry.

After factoring for accidental coincidences of AmLi gammas and neutrons with single scatter nuclear recoils in the TPC, we have a tagging efficiency of 89 ± 3 %



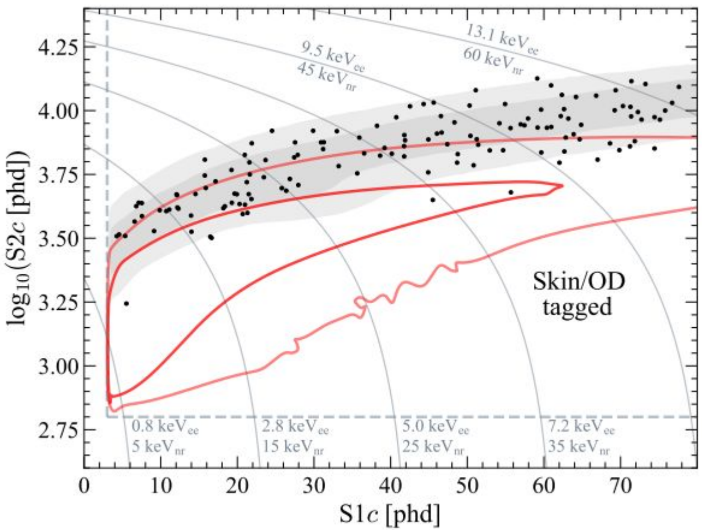


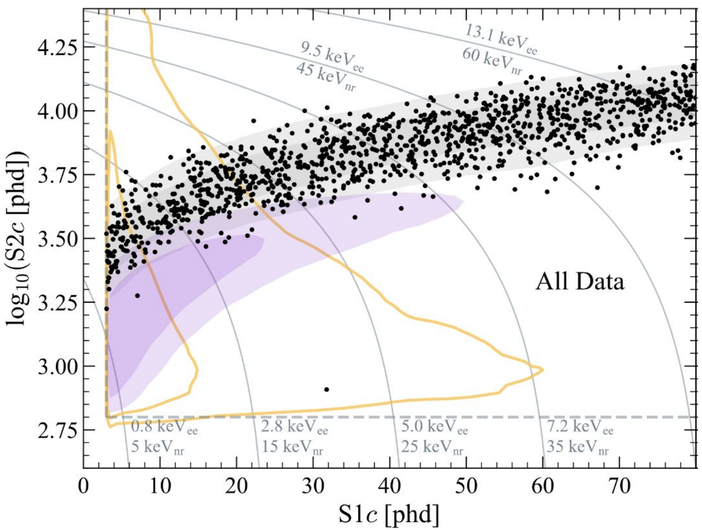




Effect on WIMP Search

- Neutron backgrounds with OD tag are 7.7 times larger than without (tagging efficiency is 89 ± 3%).
- The current veto cut only contributes 3% of the total deadtime.
- We use OD-tagged data to set constraints on neutron background rate: < 0.2 events in WS2024 result.





The Outer Detector is performing well and continues to play a key role in improving LZ's sensitivity

Thankyou!

UNIVERSITY OF LIVERPOOL

LZ (LUX-ZEPLIN) Collaboration, 38 Institutions

250 scientists, engineers, and technical staff

@lzdarkmatter

https://lz.lbl.gov/

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
- Texas A&M University
- University of Albany, SUNY
- University of Alabama
- University of Bristol
- University College London
- University of California Berkeley
- University of California Davis
- University of California Los Angeles
- University of California Santa Barbara
- University of Liverpool
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
- University of Rochester
- University of Sheffield
- University of Sydney
- University of Texas at Austin
- University of Wisconsin, Madison
- University of Zürich

US Europe Asia Oceania

Science and Technology Facilities Council

Fundação para a Ciência e a Tecnologia

SANFORD UNDERGROUND RESEARCH FACILITY

Swiss National Science Foundation

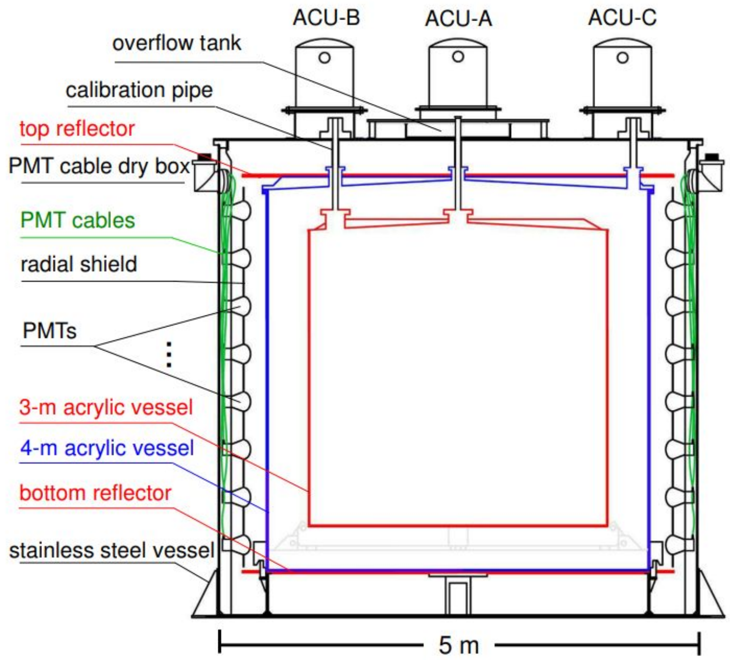
Institute for Basic Science

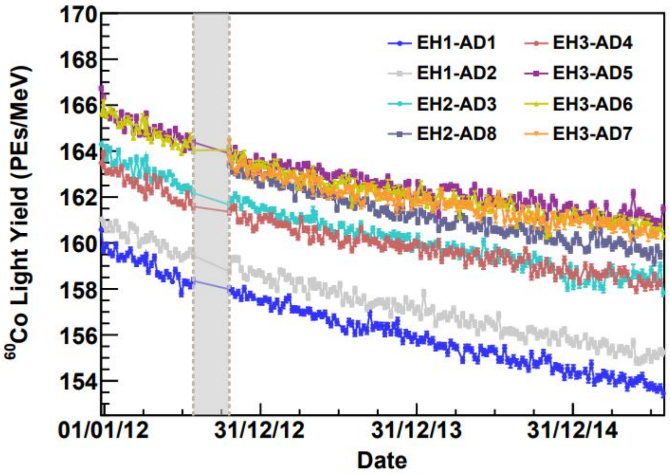
ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Thanks to our sponsors and participating institutions!

Backup

Daya Bay





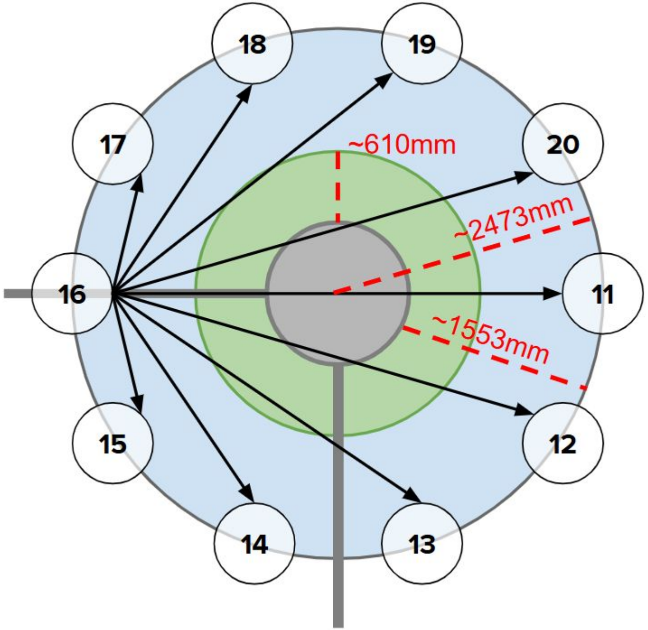
Observed light yield versus time, in units of observed photoelectrons (PEs) per MeV, as obtained using weekly deployments of a ^{60}Co source at the center of each detector.

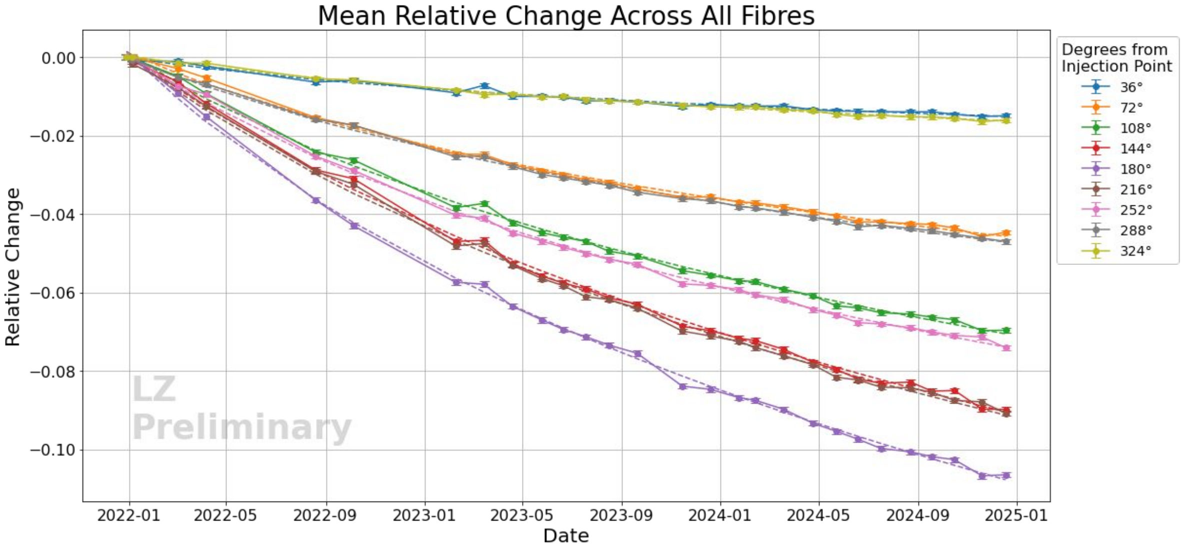
Decrease of approximately 4% over 3 years

Daya Bay Paper:
https://arxiv.org/pdf/1610.04802

The mean number of observed PEs per MeV was estimated with weekly ^{60}Co deployments at the detector center. Light yield was determined from the mean of a known gamma-ray peak in the corresponding energy spectrum, (2.506 MeV for ^{60}Co).

LUX-ZEPLIN





The further away from the fibre, the larger the decrease.

➢ **More reflection and transit through different media, the greater the reduction.**